PROBLEM AND OPPORTUNITY AREA HIGHLIGHTS

Identification of Site Needs and Science and Technology Gaps

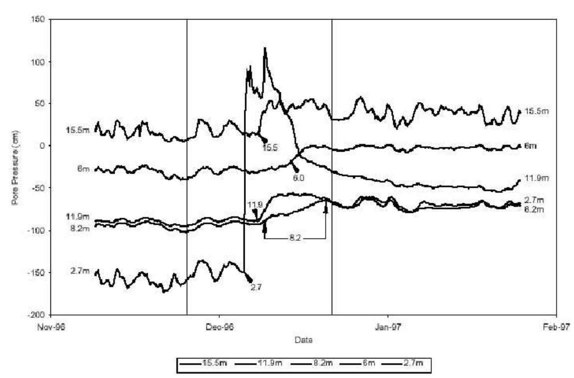
The major needs categories and special emphasis areas identified encompass numerous challenges including, but far from limited to, the **VIPs**. In this part these broad areas are examined further. It is impractical to discuss the multiplicity of individual site needs in detail within a document of manageable size. Rather, the FA approach is emulated. The FAs grouped similar needs into Needs Groups, with assistance from the crosscutting programs, and then prepared Technical Responses for the Needs Groups. Similarly, commonalities in technical approaches are often found among Needs Groups from different FAs, suggesting a crosscutting approach to meeting the needs. The Problem and Opportunity Areas presented here have been assembled using a crosscutting perspective that captures these commonalities of site needs.

In the road mapping process one typically strives to lay out a solution strategy and define a priority and a time line for each portion of the development process. This will not be attempted in this document; a major reason is the large number of science and technology development challenges and goals presented. Moreover, it is not the role of the CMST-CP to determine development priorities and schedules.

Rather than provide specific priorities and dates, therefore, this ***CMM ROAD MAP for DOE-EM*** provides simple statements that solutions will be needed or desirable in the Near-Term (within five years or so) or Far-Term (beyond five years). The benefits anticipated from developing technological solutions are stated; these implicitly delineate the consequences of failing to address the goals. Loosely speaking, the Near-Term challenges are more firmly rooted in pressing site-expressed technology development Needs, and the Far-Term challenges involve more strategic or science needs and may appear more visionary.

Nonetheless, this ***ROAD MAP*** provides a **Vision for 2012** for each of the **Problem and Opportunity Areas**. This is a vision of what capabilities could be developed and how baseline practices could change over the next ten years. The ten-year period is somewhat arbitrary, but does coincide with the target date envisioned in the Hanford 2012 Site Cleanup Vision.

APPENDIX A details specific science and technology development challenges; **Near-Term Goals** and **Far-Term Goals** associated with each of these **Problem and Opportunity Areas** are presented. Only a summary and overview of the **APPENDIX** discussions is presented here. In addition, **APPENDIX A** enumerates past OST CMM R&D successes in each area, and summarizes recent DOE-EM R&D projects.



TechID 2122: Advanced Tensiometer traces at several depths showing a precipitation event

WASTE, SOURCE, AND NUCLEAR MATERIALS CHARACTERIZATION

The long-term DOE goals of remediating environmental contamination, treating and disposing of radioactive and hazardous wastes, and decontaminating and decommissioning surplus facilities all require characterization as a first step and often as a final step as well. Accurate and thorough characterization of the nature, quantity, condition, physical extent, and hazards involved is needed for several reasons:

- to determine the scope of the remediation or treatment problem;
- to allow the selection of appropriate remediation or treatment strategies and technologies and to identify and estimate the resources needed to accomplish these tasks;
- to identify technology gaps to be closed and possible efficiencies to be obtained through the identification and development of innovative remediation and treatment methodologies;
- to ensure that remediation and treatment efforts themselves do not generate further problems;
- to provide baseline conditions from which to measure the progress of remediation and treatment efforts; and
- to foster confidence in proposed remediation and treatment programs on the part of responsible DOE site problem holders, DOE itself, Congress, and the Administration as well as regulatory and stakeholder communities and the general public.

The drawbacks of traditional characterization procedures affect all aspects of characterization in the DOE complex. These generally involve <u>sampling</u> materials according to a <u>predetermined plan</u>, <u>shipping</u> samples off-site for <u>later</u> and typically <u>costly</u> laboratory analysis, and disposing of <u>secondary wastes</u> generated in the process. These drawbacks include

- the difficulty of obtaining <u>representative samples</u> of heterogeneous materials such as those found in high-level waste tanks, certain types of subsurface regions, containerized wastes of unknown origin, and regions with restricted access such as small pipes and ducts;
- the inability to use results from recent samples incrementally in <u>dynamic planning</u> of the characterization effort, due to the <u>delay</u> incurred while awaiting off-site laboratory results;
- <u>costs</u> associated with the need to consider every sample as potentially hazardous while sampling and shipping and with the <u>post-analysis disposal</u> of potentially hazardous samples;
- the lack of <u>economies of scale</u> which might be obtained with the large numbers of analyses to be performed during the course of the DOE environmental management and cleanup effort; and
- the requirement that <u>every</u> sample be analyzed for the entire list of potential contaminants, even after the actual constituents of concern and their nature have become well understood.

Not each of these applies in every case, of course, but at least some apply in virtually every DOE-EM characterization task. Innovative characterization methodologies overcome these drawbacks in a number of ways, including

- the use of relatively <u>inexpensive *in situ* sensors</u> to generate a greater data density as one means of addressing the <u>heterogeneity</u> problem;
- the use of <u>autonomous real-time *in situ* sensors</u> to avoid delays between sampling and availability of analytical results, allowing <u>dynamic planning and control</u> with frequent on-site decision making for characterization, remediation, and treatment projects;

- the use of on-site and *in situ* methods to minimize or eliminate secondary wastes with their attendant risks of personnel exposure;

- the use of holistic and tomographic measurements to avoid the uncertainties associated with sampling heterogeneous media; and

- the use of minimally invasive and non-invasive/nondestructive methodologies which avoid personnel exposure and secondary waste generation.

These approaches and their underlying scientific and engineering principles are crosscutting foundations on which DOE-EM characterization science and technology advances can be based. These are applied to each of the Needs Groups.

Characterization of Contamination Sources

Contamination at DOE sites exists primarily in the subsurface and in contaminated facilities. Subsurface contamination sources include waste burial grounds, trenches, and pits along with previously contaminated soils and groundwater. The initial task involves locating these sources and delineating the nature and extent of contamination present. Non-invasive remote surface sensing and geophysical techniques have proven useful for identifying possibly contaminated areas for further investigation. Areas identified using such techniques must be investigated further while planning remediation activities. The variety of challenges faced results from the variety of modes of contamination present: undocumented waste drums buried in pits; leakage from production processes into the soils underneath buildings; seepage from unlined or leaking waste lagoons and underground storage tanks; leaching into the soils from surface contamination; and so on.

Subsurface contamination. Two prominent long-range goals in this regard are (a) developing improved understanding of the subsurface science involved in predicting contaminant transport and fate and (b) developing better ways of locating and characterizing distributions of Dense Non-Aqueous Phase Liquids (DNAPLs). The first of these involves developing satisfactory methods for modeling to predict contaminant flow toward, with, and sometimes contrary to groundwater in the subsurface; this is discussed further in **Improved Scientific Understandings**. The DNAPL problem deserves a separate category because DNAPLs (typically toxic chlorinated organic compounds) dissolve only sparingly in groundwater, so the usual groundwater flow models do not apply. Moreover, DNAPL contamination, once present, can remain in the subsurface for decades or longer.

Once the nature and extent of contamination have been determined and a remediation approach selected, the remediation process must be monitored; see the next section **Process and Product Monitoring**. When cleanup activities are complete, further characterization is typically required to determine or verify the end result of the cleanup operation: that the site can be released for unrestricted future use; or, alternatively, that the site satisfies the requirements placed upon it for entry into a long-term stewardship mode. Establishing and determining the adequacy of those long-term stewardship requirements again requires advances in understanding of contaminant fate and transport in many instances. These end-state characterization requirements apply as well when the decision is that no (further) remediation is warranted at a site.

Contamination in and on facilities. Contamination on surfaces and embedded within facilities slated for deactivation and decommissioning (D&D) presents similar challenges. In facility D&D there is the added challenge of performing characterization in difficult to access areas: inside walls, pipes, ducts, and equipment. In this setting great benefits may be realized by replacing conventional sampling and laboratory analysis with real-time, *in situ* measurement and mapping. Many past OST CMM R&D successes have involved technology development for non-invasive real-time radiation measurements; goals presented here include extending these capabilities with respect to both the variety of contaminants that can be measured and the ease with which the measurements can be made.

Characterization of Waste and Nuclear Materials

Another major characterization area is that of wastes and nuclear materials, including spent nuclear fuel. Whereas contaminant source characterization has previously been a major concern of only the Subsurface Contaminants Focus Area (SCFA) and the Deactivation and Decommissioning Focus Area (DDFA), waste and nuclear material issues cut across all DOE-EM operations and are a major concern for many. Characterization issues and methods can in many instances be quite similar to monitoring issues and methods; the operational distinction is that monitoring is generally an on-going activity, whereas characterization typically takes place during a few events of limited duration.

High-level waste tank remediation. Remediation of tanks containing high-level waste (HLW) is a critical DOE-EM technical and programmatic challenge. Prominent characterization needs arise at all stages of remediation: ensuring storage tank integrity while awaiting treatment; ensuring reliable, safe, and efficient waste retrieval; determining tank residues following waste retrieval; determining waste composition in order to plan stabilization into an appropriate final waste form; and characterizing the final waste forms to verify their intended composition and durability. Three related specific need areas have been identified: (1) sampling methodologies for tank residues, tank waste slurries, and stabilized waste forms; (2) improved laboratory analytical procedures for situations in which current methods are excessively slow or expensive or do not provide adequate sensitivity; and (3) *in situ* characterization for situations where sampling for laboratory analysis is not feasible because results are needed promptly or because representative sampling is not possible. A fourth need area is evaluation of the HLW tanks themselves to ensure maintenance of tank integrity.

An alternate approach to high-level waste tank disposition involves *in situ* stabilization and closure. The characterization needs associated with this approach are different from those involved with waste retrieval; major components include (1) waste volume determination; (2) characterization of the radionuclide inventory and identification of suitable indicator species or parameters for post-closure monitoring; and (3) evaluation of tank structural integrity.

Waste and nuclear material long-term storage. HLW, mixed waste, and certain nuclear materials are all stabilized and packaged for transportation and long-term storage. It is necessary to characterize the feedstock for these treatment and stabilization processes (e.g. incineration, calcination, or vitrification). The final waste form must be verified to meet transportation requirements and the Waste Acceptance Criteria (WAC) or Land Disposal Restrictions (LDR) of the repository sites. Moreover, methods are needed for monitoring the continued integrity of these waste forms; see **Process and Product Monitoring**.

Other waste characterization challenges. Additional specific challenges of note involve characterizing wastes generated by remediation processes themselves, characterizing waste sources (notably facilities slated for D&D) in order to effect volume reduction, and characterizing containerized wastes. The last of these is discussed further in **Nondestructive Methods**. Remediation and D&D efforts need to be closely coordinated with treatment, transportation, storage, and/or disposal planning.

The Deactivation and Decommissioning Free Release Goal

Several related challenges are identified in this area. The first set involves efficient real-time *in situ* characterization of facilities, equipment, and containerized materials to distinguish between contaminated and non-contaminated areas and materials and to identify contamination where it exists. The goal of these methods is to quickly and accurately determine whether a particular portion of a facility can be considered for reuse rather than dismantlement or demolition or, failing that, how the D&D project should proceed most efficiently with respect to volume reduction as well as worker and public safety concerns. Ideally such characterization would be done simultaneously with facility D&D activities, using sensors capable of reliably providing regulatorily acceptable measurements down to the D&D Free Release Goal. Such a capability would, of course, blur the distinction between facility characterization and D&D process monitoring.

Special challenges involve characterization of inaccessible areas inside pipes, cavities, ducts, and equipment as well as areas that present excessive hazards in terms of personnel exposure. One strategy involves expanding the use of robotic methods in the characterization of both inaccessible and hostile areas. In both of these one must develop real-time *in situ* sensors with adequate sensitivity, and obtain regulatory acceptance for their application.

Regulator and Stakeholder Concerns

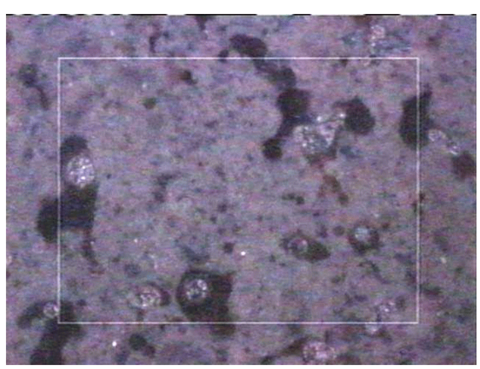
A common thread to all characterization and monitoring tasks is the need to secure regulatory and stakeholder acceptance of the methods used. This must be kept in mind while developing innovative approaches that depart from traditional baseline methods. A particular issue involves dealing with evolving regulatory standards. A particular useful technique for meeting these challenges is to collaborate with regulatory agencies in the development and validation of innovative methods.

A Vision for 2012

Within ten years DOE-EM should have developed the ability to characterize any non-negligible amount of contamination. *In situ* characterization of radionuclides will be enhanced through both incremental and step-change improvements in sensors coupled with innovative methods of deploying those sensors in limited access areas inside buildings, tanks, pipelines and ducts, building grounds, and landfills. *In situ* characterization of hazardous constituents will require major advances in field-deployable instrumentation; these should be achievable through improvements in sampling techniques and miniaturization of successful laboratory technologies. Robotics technologies will be necessary in some settings and very desirable in others.

Characterization of subsurface processes and contaminant distributions should enable credible long-term planning in support of site closure and long-term stewardship. Such planning will involve superior delineation of the nature and extent of subsurface contamination along with a better understanding of the natural processes affecting the fate and transport of that contamination and of ways to correlate anticipated fate and transport with available information about subsurface geology, geochemistry, and hydrogeology. Subsurface characterization will rely increasingly on non-invasive (geophysical) and minimally invasive (direct push) methods coupled with sophisticated analysis algorithms. Robotic and other remote and/or automated characterization methodologies will reduce risks to workers and increase efficiencies.

Improved data management and analysis models and protocols (data fusion) will replace current procedures centered around sample collection, laboratory analysis, and interpretation which often focus on individual constituents. Involvement of stakeholders and regulators should accompany these developments at each step to ensure that these improved capabilities are appreciated and employed. Regulator and stakeholder acceptance could be assisted by open, web-based reporting.



TechID 2399: GeoVis^{TM} View of DNAPL in the subsurface

PROCESS AND PRODUCT MONITORING

Once the site or facility has been characterized and an environmental management or cleanup strategy decided upon, the task turns from characterization to monitoring, which is the systematic tracking of repeated measurements to detect and quantify changes. Monitoring is an integral part of environmental management and remediation activities for several reasons:

- to determine and document the evolution of the system being monitored;

- to warn of unanticipated or adverse events or trends occurring in the system; and

- to verify the effectiveness of remediation or treatment processes and, if necessary, to provide an alert when the processes are no longer performing as intended.

Monitoring is required for virtually every environmental management activity. Past monitoring practices share many of the previously enumerated drawbacks of past characterization practices; indeed, some of those drawbacks are even more important for monitoring than for characterization. Moreover, the demands of real-time monitoring for some treatment processes go far beyond those imposed by initial or final characterization. These drawbacks include

- the virtual uselessness of off-site laboratory analyses in treatment and remediation process control due to the inherent delay between sampling and data availability, resulting in a need to rely on inefficient feed-forward process control when on-line feedback control would be preferable;

- the costs associated with personnel protection and disposal of secondary wastes when monitoring through sample collection, as well as those associated with using conventional methods in providing the very large number of measurements anticipated in the DOE environmental management and cleanup agenda rather than achieving economies of scale through the use of innovative technologies;

- the risks posed by potential breakdowns of treatment processes such as slurry pipeline blockages or emissions, which might be avoided if better monitoring procedures were available;

- the need to rely solely on post-process sampling of final waste forms or nuclear material forms to verify process success when continuous process monitoring is not available;

- a similar need to rely on post-cleanup verification of facility decontamination, possibly followed by further decontamination stages, when real-time verification of cleanup success would allow project completion in a single stage; and

- the difficulties with emerging requirements in regulatory compliance and stakeholder acceptance with regard to off-gas effluents from thermal treatment, alternative oxidation treatment, and other waste and nuclear material stabilization processes.

The purpose of CMM Science and Technology development for process monitoring is to overcome these drawbacks. Numerous specific goals are discussed in succeeding sections and especially in **APPENDIX A**. Several common threads run through these goals, including

- the use of real-time, *in situ* sensors to minimize sample collection, time delays, exposure risk of personnel, and secondary waste generation;

- the incorporation of real-time sensors into waste and nuclear material stabilization processes in order to provide continuous process control and documentation and to avoid the risk of process breakdown;

- the improvement of laboratory analytical methods with regard to cost, time, and sensitivity;

- cost reduction resulting from the large-scale use of inexpensive *in situ* sensors and on-site analyses in place of conventional laboratory analyses; and

- avoidance of costs in remediation verification due to the availability of reliable, acceptable data obtained during the remediation process.

High-Level Tank Waste Processing

Vitrification had been tentatively identified as a candidate treatment for high-level tank wastes, although the high cost and technical risks of the process continue to spur a search for viable alternatives. Process monitoring will be critical to tank waste vitrification or any other treatment. Safety, efficiency, and cost reduction can be enhanced by reliable real-time monitoring of the feed, intermediate products, and final products of each stage of the remediation process selected. Real-time monitors are needed to detect possible leaks during retrieval and to measure slurry properties to ensure mixing status and reliable pipeline transfer. After retrieval and possibly pretreatment, the HLW or its intermediate products will undergo further processing, such as stabilization. Existing stabilization processes depend on careful control of feedstock, which limits the production rate; feedback process control would allow considerable increases in efficiency. This area is at the basic science stage of development at present; development of real-time monitors is a far-term goal.

Mixed and Mixed Transuranic (TRU) Waste Treatment

Mixed wastes contain both hazardous and radioactive components. The hazardous components include toxic organic compounds and heavy metals. The organic constituents can be destroyed by oxidation or other treatments, after which the residue can be stabilized for long-term isolation.

Monitoring of treatment processes. The challenges here are to verify the completeness of the destruction of organic constituents and to ensure that any effluents from the treatment processes satisfy regulatory requirements. Emissions standards and protocols for incinerators are currently in place, although the EPA is beginning to encourage alternate protocols based on continuous emissions monitors (CEMs). CEMs for regulated constituents are becoming available, although further development work is needed in several areas. Protocols and standards for monitoring effluent emissions for treatment technology alternatives to incineration are being developed through joint research involving the EPA, DOE, and other participants. One aspect of this research involves studying the formation of certain toxic organic constituents (dioxins and furans) during the oxidation process itself for the purpose of limiting the creation of these constituents; see **Improved Scientific Understandings**.

Waste and Nuclear Material Stabilization

Once the organic component of mixed waste has been removed, or HLW has been pretreated to remove certain radioactive constituents, the wastes are stabilized for long-term storage through vitrification or another solidification process. There is an urgent need for *in situ* real-time monitoring of the vitrification or solidification process to provide feedback for process control. The goal of such process control is to ensure that the process product will meet the specifications for long-term storage. Lacking such on-line process control, the process operators must rely on careful characterization of feedstock materials and engineering controls on the vitrification process, followed by sampling and laboratory analysis of the product and possible reprocessing if long-term storage criteria are not met. As with other applications involving *in situ* real-time measurements, regulatory acceptance will be needed to achieve the benefits of the innovative technology.

These same needs apply for stabilization of nuclear materials for future use; indeed, the final product criteria may be stricter because of the intended final use. In addition, it will be desirable to develop nondestructive and automated methods for inventory control of the stabilized materials.

Monitoring of Soil and Groundwater Remediation

These monitoring needs complement those for soil and groundwater characterization. As with facility D&D, the anticipated benefits are greatest for real-time *in situ* measurements that can make reliable process control possible during remediation. Several specific challenges have been identified: real-time determination of radioactive and other contaminants in soils during excavation, to support precise and defensible control of the volumes of soils excavated; inexpensive *in situ* monitoring of the extent of DNAPL and other contaminant plumes during remediation, leaving more costly sampling and laboratory analyses to final verification, if indeed it is even needed at that stage; and real-time monitoring of remediation processes which do not remove contaminated materials (particularly DNAPLs) from the subsurface but rather treat them in place.

In addition to active remediation of the subsurface, DOE facilities will require long-term monitoring in certain situations: passive treatment systems such as natural attenuation or enhanced natural attenuation; containment systems such as landfills, subsurface barriers, and tanks; and post-cleanup monitoring once cleanup activities have been completed, if the facility cannot be returned to free-release status; see **Long-Term Monitoring** to follow.

Monitoring of Facility Deactivation and Decommissioning

Ideally these monitoring needs will become nearly identical with characterization needs in a future in which real-time *in situ* measurement systems allow dynamic process control and optimization of treatment systems, efficient waste segregation for volume reduction of HLW and LLW, more reliable worker protection, and cost savings resulting from both reduced analysis costs and waste volume reduction.

A Vision for 2012

By 2012 DOE-EM should be able to treat wastes and nuclear materials on a reasonably routine production basis, using data provided by *in situ* real-time sensors as nearly the sole means documenting regulatory compliance. Current challenges of avoiding pipeline slurry blockages, ensuring waste tank and container integrity as long as necessary, and controlling and avoiding effluent releases of hazardous materials will no longer be challenges; reliable autonomous, self-reporting alarm systems will be in place to accomplish this end.

Strategies for efficient monitoring of subsurface remediation processes will have been developed and will have met with broad, if not universal, end user and regulatory approval. These strategies will tend toward *in situ*, autonomous, self-reporting and self-testing sensors with appropriate data collection, screening, and event generation provisions. A new generation of sensors will be needed for this and particularly for the demands of long-term stewardship; see the following section.

TechID 2015: Integrated Raman-EN Sensor for Tank Corrosion Chemistry Monitoring

LONG-TERM MONITORING

In recent years the need for long-term stewardship has become increasingly apparent, due to the impossibility or impracticality of cleaning up many DOE sites adequately for release for unrestricted use. Such sites include engineered facilities and containment systems as well as sites with existing subsurface contamination. In addition, the treatment of choice for certain types of contaminants, notably organic constituents, may well be natural or enhanced natural attenuation, again requiring long-term monitoring to verify that the process is progressing as anticipated and to provide alerts if needed. The demands of long-term monitoring differ from those of traditional monitoring of waste management facilities in several significant ways:

! traditional monitoring is based on sample collection and shipment to on-site or off-site laboratories, whereas it would be highly desirable to minimize the logistical demands of actual sample collection and shipping during long-term monitoring;

! the record-keeping involved in traditional monitoring involves sampling logs, chain-of-custody forms, laboratory analysis records, and facility management reports to regulatory authorities, whereas during long-term monitoring using remote and automated systems it will be highly desirable to minimize the "paper-work" involved while maintaining legal defensibility;

! monitoring at active sites, particularly waste management sites, is typically designed to detect releases of any of a large suite of potential contaminants whose source concentrations may increase or decrease in time, whereas during long-term monitoring the source will have been well characterized so that the monitoring program can be more specifically targeted; and

! traditional monitoring is typically performed at or near sites or facilities with on-going activities and related personnel and other resources, whereas it will be highly desirable to limit the personnel and other on-site resource demands during long-term monitoring.

Conventional monitoring technologies and strategies could be used in long-term monitoring, but their use is expected to be inefficient and costly. Among the drawbacks of traditional monitoring approaches are the following:

! the need for routine periodic <u>hands-on</u> field sampling at many locations rarely if ever visited otherwise;

! the typical reliance on a <u>broad array</u> of indicator parameters and potential contaminants rather than a <u>short list of key indicators</u> based on <u>detailed knowledge of site-specific conditions</u> and processes;

! the need to <u>ship samples</u> to off-site laboratories, with attendant shipping costs and, in some cases, exposure risk;

! the cost savings lost by not taking advantage of potential <u>economies of scale</u> when dealing with the great numbers of similar measurements which will need to be made and processed during DOE long-term monitoring activities; and

! the need for <u>manual review</u> of laboratory reports and other documents.

Many advances in monitoring technology and procedures will be desirable to overcome these drawbacks and carry on long-term monitoring efficiently. General goals include the following:

! advancing the ability to <u>characterize</u> subsurface contamination, subsurface contaminant flow, and the site-specific processes which affect contaminant fate to identify defensible parsimonious lists of key indicators to monitor;

- developing remote, *in situ*, relatively low-unit-cost sensors capable of autonomous reporting, self-maintenance, and self-validation for selected parameters appearing on the short parameter lists;

- developing automated data collection, recording, storage, review, and event reporting capabilities which will minimize the logistical demands of dealing with long-term monitoring data; while

- encouraging the evolution of regulatory paradigms involving parameter selection, data and decision quality, data storage, and event reporting as appropriate for the advanced monitoring systems envisioned.

Long-Term Monitoring Challenges

The major science and technology innovation needed for efficient long-term monitoring is the invention of a new generation of sensors. The new sensors will be rugged, to withstand long deployments in possibly hostile environments; small, for *in situ* deployment using the cone penetrometer and GeoProbe™ as well as for reduced energy demands; self-validating and self-maintaining, to minimize maintenance demands while assuring monitoring system and data integrity; and capable of remote autonomous reporting.

An additional demand is that of shifting the monitoring paradigm from active, hands-on monitoring to passive, remote monitoring. This will require better understanding and modeling of subsurface processes involved in contaminant fate and transport as well as careful site characterization in order to justify and validate efficient, parsimonious monitoring program designs. Advancing data recording storage, validation, retrieval, analysis, and event reporting are also needed. These advances will be needed to gain regulatory and stakeholder acceptance of the new and efficient monitoring systems.

A Vision for 2012

An optimistic vision for DOE-EM capabilities by the year 2012 has long-term monitoring in support of long-term stewardship and passive remediation using a new generation of robust sensors capable of unattended operation, autonomous reporting, self-calibration and testing (even self-repairing to some extent), and minimal or no reliance on consumable supplies or external power. These sensors will be linked to remote data acquisition systems; data will be recorded, validated, and screened nearly automatically; sophisticated decision rules will govern the generation of alarms for exceptional events that require human recognition and intervention.

Superior understandings of fate and transport processes will have enabled a substantial evolution of regulatory paradigms from the current practice of monitoring extended, general lists of parameters to the judicious, parsimonious selection and monitoring of key site-specific indicator parameters. All of these advances will have been accomplished on multiple fronts: challenges are faced in both the technical and the regulatory and stakeholder acceptance arenas.

TechID 3182: Chemiresistor for VOC monitoring

NONDESTRUCTIVE METHODS

Nondestructive Assay and Nondestructive Evaluation (NDA and NDE) techniques range from visual examination and calorimetric measurements to high-energy gamma-ray measurements. Typical NDA methods involve gamma and passive or active neutron spectroscopy for isotope determination and mass quantitation of nuclear materials and TRU/Mixed TRU waste. NDE is typically performed by digital radiography. Ultrasound NDE may be employed for characterization of tank integrity, for example.

Many NDA and NDE techniques measure radiation from a target in order to determine its physical and chemical properties. This radiation may be emitted spontaneously (passive NDA/NDE), as radioactive emissions from radionuclides or thermal emissions from heated materials, or in response to an external stimulus (active NDA/NDE), as with laser-induced fluorescence (LIF), laser-induced breakdown spectroscopy (LIBS), and pulsed gamma neutron activation analysis (PGNAA). X-ray or LIF imaging technologies may be used to examine inside pipes or survey facility walls, respectively. In some cases the radiation emitted uniquely identifies the isotope(s) present and can thereby be used in quantitation.

The baseline technology is typically conventional destructive analysis; i.e., sampling followed by laboratory chemical or radiological analysis. Reasons for preferring NDA/NDE over baseline technologies include

- the lack of material destruction, which is critical in applications involving inventory control of nuclear materials;
- the avoidance of sampling and the time delays and secondary wastes inherent in sampling followed by laboratory analysis;
- the reduction in radiation and hazardous material exposure for personnel;
- the availability of analytical results in real time or near-real time, making them useful for process control or real-time planning of process or remediation activities;
- the holistic analysis of heterogeneous materials, in situations where representative sampling might be challenging; and most significantly
- the ability to view inside materials or objects in certain circumstances, such as non-invasive examination of tank walls, pipes, and ductwork in facilities undergoing D&D, and waste in containers.

Many early OST CMM R&D successes involved spectral methods of various types, many of which can be considered as variants on the NDA/NDE theme; see **APPENDIX A**. Advances desired in this area include

- advancement of neutron capture and combined gamma-neutron interrogation techniques for evaluating containerized wastes for radionuclides and RCRA metals;
- fusion of NDA/NDE analysis results with acceptable knowledge from the facility operating record;
- fusion of tomographic X-ray evaluation and neutron-gamma NDA assay;
- development of NDA/NDE methods for monitoring HLW storage tanks;
- development of methods for verifying the continued safe storage and inventory of containerized nuclear materials, particular with regard to moisture content and hydrogen headspace gas concentration; and
- development of NDA methods for assay of contaminants in bulk materials such as concrete and in microscopic structures such as surface cracks in metals during facility D&D.

NDA and NDE for Mixed and Mixed TRU Wastes

Priorities in NDA/NDE method development include analyses of containerized wastes for radionuclides and RCRA metals and analyses of remote-handled wastes, combining direct measurements with acceptable knowledge. Cost effective radiological classification and disposal of TRU waste lacks simple and demonstrated *in situ* measurement and verification procedures. Overly restrictive classifications can be assigned in the absence of defensible measurements. The differences in disposal costs can vary substantially between TRU and LLW. A combination of process information (Acceptable Knowledge), simple measurements, and calculated predictions from radiation shielding models may readily resolve issues on many waste streams. Some RH waste streams may require developing advanced characterization methodology. NDA measurements are influenced by many variables, including type of radiation and energy, measurement distance, source size and shape, source distribution and matrix, and shielding. Since the signal depends on the elemental composition of the material interrogated, as well as a host of measurement geometry and shielding considerations, sophisticated matrix-correction algorithms are needed.

High-Level Waste Tank Integrity

Needs here focus on better understanding of corrosion and failure mechanisms of HLW tanks in order to prevent leaks in the future, and on monitoring aging in-use HLW tanks for years or decades until final closure.

Nuclear Materials and Spent Nuclear Fuels

Challenges here focus on assay of nuclear materials and spent nuclear fuel for inventory control and regulatory certification, as well as NDE of containerized materials to ensure their continued safe storage.

Non-Intrusive Techniques for Facility Deactivation and Decommissioning

The focus for NDA/NDE science and technology development for facility D&D is in developing methods for detecting radionuclides and hazardous materials inside materials in support of worker safety and volume reduction of HLW and LLW.

Vision for 2012

By 2012 DOE-EM attentions will have shifted largely from initial characterization to remediation, facility closure, and long-term stewardship. NDA/NDE and robotic methods should become the baseline for routine characterization and monitoring in many settings. NDA/NDE methods will be thoroughly embedded in the processes for treatment of mixed, mixed TRU, and high-level tank wastes and nuclear materials. Non-intrusive methods will have been developed to the point of facilitating reliable evaluation and assay of closed containers with regard to radionuclide as well as hydrogen and moisture content. The use of NDA/NDE methods for tank integrity monitoring and tank residual waste verification should be routine.

TechID 134: X-Ray K-Edge Heavy Metal Detector

IMPROVED SCIENTIFIC UNDERSTANDINGS

Three topics deserve special attention.

Subsurface Science

Long-term stewardship and site closure often require and depend on models of contaminant fate and transport in the subsurface. Research is needed to understand subsurface processes better, with an eye toward making reliable fate and transport predictions. With a better understanding of the processes will come an enhanced ability to determine the key predictive characteristics and parameters of those processes and how to better characterize them.

Emerging and Evolving Technologies

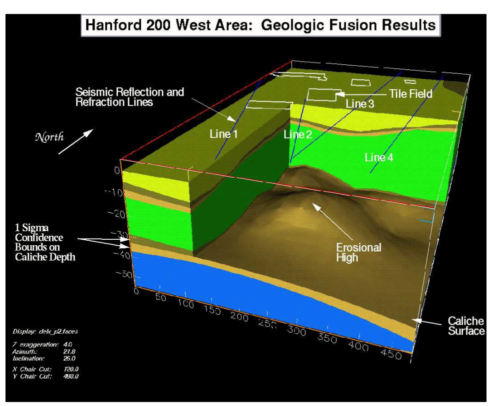
The year 2002 is an exciting time in sensor technology development, with advances in miniaturized sensors and biosensors among others being made in government, industry, and university laboratories. Many of these emerging technologies, along with evolutionary advances in currently available technologies, are of critical importance to DOE in pursuing its environmental management, cleanup, and long-term stewardship mandates. DOE-EM should remain aware of and encourage these developments and steer them toward DOE applications. In addition, DOE-EM should promote continual evolution in characterization and monitoring strategies and regulatory paradigms to parallel the technological advances.

Data Collection and Interpretation

Finally, the availability of the new breed of sensors, particularly those suited to **Long-Term Stewardship** applications, will demand new ways of dealing with data collection (remotely, autonomously), storage (automated, but with adequate data verification and authentication), validation (by remote sensors themselves and by the data access and storage system), and screening, analysis, and reporting (automated, using site-specific decision rules). New visualization systems will be of great benefit in some contexts. Along with these new ways of handling and reporting data will come need for a parallel evolution in regulatory requirements, which in turn will require adequate demonstration and validation of the proposed data collection and interpretation systems.

A Vision for 2012

By 2012 these specific special challenges will have been met, although improved sensor development will always continue. These three areas will have had major impacts on characterization and monitoring in general, and the knowledge gained by DOE and disseminated through collaboration with EPA, DoD, and other agencies will have had a substantial impact in streamlining regulatory and stakeholder acceptance.



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